Cotton Planting Date Affects the Critical Period of Benghal Dayflower (*Commelina benghalensis*) Control

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Benghal dayflower (formerly known as tropical spiderwort) is one of the most troublesome weeds in Georgia cotton. Field studies were conducted from 2003 to 2005 to evaluate the relationship between the duration of Benghal dayflower interference and cotton yield to establish optimum weed-control timing. To determine the critical period of weed control (CPWC), Benghal dayflower interference with cotton was allowed or prohibited in 2-wk intervals between 0 to 12 wk after crop planting. Maximum yield loss from Benghal dayflower in May-planted cotton was 21 to 30% in 2004 and 2005, whereas cotton planting delayed until June resulted in maximum yield losses of 40 to 60%. June-planted cotton had a CPWC of 190 to 800 growing degree days (GDD) in 2004 (52-d interval beginning at 16 d after planting [DAP]) and 190 to 910 GDD in 2005 (59-d interval beginning at 18 DAP). In contrast, May-planted cotton in 2005 had a narrower CPWC interval of 396 to 587 GDD (18 d) that occurred 3 wk later in the growing season (initiated at 39 DAP). May-planted cotton in 2004 did not have a critical range of weed-free conditions. Instead, a single weed removal at 490 GDD (44 DAP) averted a yield loss greater than 5%. It is recommended that fields infested with Benghal dayflower be planted with cotton early in the growing season to minimize weed interference with the crop.

Nomenclature: Benghal dayflower (tropical spiderwort), *Commelina benghalensis* L. COMBE; cotton, *Gossypium hirsutum* L.

Key words: Competition, interference, exotic weed, Federal Noxious weed, nonnative weed, planting date, yield loss.

Benghal dayflower (formerly known as tropical spiderwort) is native to tropical Asia, Africa, and the Pacific islands (Faden 2000) but has become a significant weed throughout warm temperate regions in portions of Australia, North America, and South America (Holm et al. 1977; Webster et al. 2005; Wilson 1981). In the southeast United States, Benghal dayflower has become one of the most troublesome weeds in cotton and peanut (*Arachis hypogaea* L.) of Georgia and Florida (Webster 2005), with known occurrences in Alabama, Louisiana, Mississippi, North Carolina, and South Carolina (Faden 2000; Krings et al. 2002; Webster et al. 2005). Benghal dayflower infests at least 80,000 ha of crop land in Georgia and has been identified in 42 counties (Culpepper et al. 2008; Webster et al. 2006). Benghal dayflower has become a significant pest because of the adoption of glyphosate-tolerant crops, which precipitated changes in crop production practices. Some of these changes included elimination of the use of herbicides at planting with soil residual activity; adoption of reduced tillage (coupled with elimination of cultivation as a weed control tactic); and reliance on glyphosate-only systems for weed control (Brecke et al. 2005; Culpepper 2006; Mueller et al. 2005; Spader and Vidal 2000; Webster et al. 2005). In a recent survey of weed scientists from 11 states in the United States, 50% of the respondents indicated that *Commelina* species were an increasing problem in glyphosate-resistant crops (Culpepper 2006). This can be partially attributed to ineffective control of this species with glyphosate; glyphosate controlled 3 to 10-cm-tall Benghal dayflower less than 55% (Culpepper et al. 2004). The lack of glyphosate activity on Benghal dayflower, coupled with the nearly total adoption of glyphosate-resistant cotton varieties and subsequent glyphosate use, provided a selection pressure that has benefited this troublesome weed.

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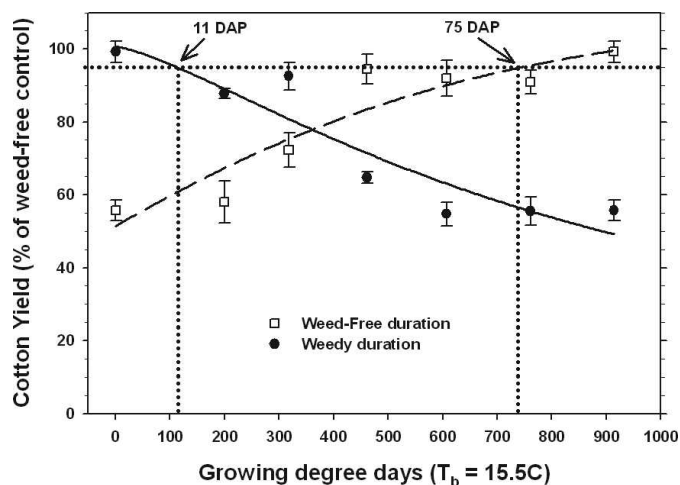
Full-season interference of Benghal dayflower, at a density of 10 plants m^{-2}, reduced cotton yields by 40 to 62% in West Africa (Ahanchede 1996). Numerous studies have evaluated the relationship between the density of various weeds and cotton crop yield losses, many of which were included in a review by Askew and Wilcut (2002). However, there have been only a limited number of studies that have evaluated the critical period of weed control (CPWC) in cotton (Buchanan and McLaughlin 1975; Buchanan et al. 1977; Bukun 2004; Papamichail et al. 2002; Snipes et al. 1987; Tingle et al. 2003). The CPWC for Benghal dayflower in cotton has not been quantified. Previous studies have demonstrated that cultural crop production practices (e.g., fertilization regime, row spacing, and planting date) can influence weed–crop interactions and duration of the CPWC (Evans et al. 2003; Klingaman and Oliver 1994; Knezevic et al. 2003; Williams 2006). Therefore, the objectives of this study were to quantify the critical period of Benghal dayflower control required in cotton to optimize weed control timing and evaluate whether crop planting date affects CPWC.

Materials and Methods

Studies were conducted near Cairo, GA (30°59′20″N, 84°16′57″W) in 2003, 2004, and 2005 in fields with naturalized populations of Benghal dayflower. Soil type was Tifton loamy sand (fine-loamy, kaolinitic, thermic Kandiudults) with organic matter ranging from 0.9 to 2.0% and pH ranging from 5.7 to 6.4. Plots were 7.6 m in length and four rows wide, with rows spaced 91 cm apart. Fields were conventionally prepared by harrowing followed by a combination in-row subsoiler (set to a depth of 45 cm) with a bed-shaper. Cotton was planted on April 30, 2003, May 18, 2004, June 13, 2004, May 12, 2005, and June 18, 2005 with a hill-drop planter that spaced three cotton seeds every 28 cm. The cotton variety planted in April and May was 'DP555 B/RR', currently the most commonly planted variety in Georgia, whereas June cotton was planted with 'DP424 B2/RR', a short-season variety. Pendimethalin at 930 g ai ha^{-1} was

Figure 1. The relationship between cotton yield in 2003 and duration of both Benghal dayflower–present [$y = 101/(1 + (X/886)^{1.37}$; $R^2 = 0.80$, P < 0.0001] and Benghal dayflower–free intervals ($y = 111 \times \exp\{-\exp[-(x + 123)/462]\}$; $R^2 = 0.73$, P < 0.0001). The dotted horizontal line indicates 5% yield loss. The critical period of Benghal dayflower control is defined by the position at which each of the regression curves intersects the 5% yield line; the beginning and end of the interval is indicated in days after cotton planting (DAP).

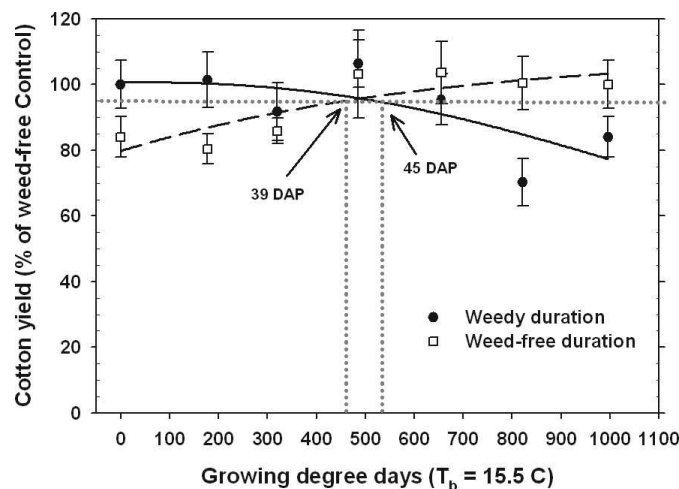
Figure 2. The relationship between May-planted cotton yield in 2004 and duration of both Benghal dayflower–present ($y = 101/[1+(X/1,614)^{2.5}$; $R^2 = 0.51$, P = 0.0240) and Benghal dayflower–free intervals ($y = 109 \times \exp\{-\exp[-(x + 644)/547]\}$; $R^2 = 0.67$, P = 0.0091). The dotted horizontal line indicates 5% yield loss. The critical period of Benghal dayflower control is defined by the position at which each of the regression curves intersects the 5% yield line; the beginning and end of the interval is indicated in days after cotton planting (DAP).

applied to the experimental area to control small-seeded broadleaf and grass weeds; previous studies have demonstrated that pendimethalin has no effect on Benghal dayflower (Culpepper et al. 2004). Standard cultural practices for Georgia, such as fertilization, insect management, and cotton plant growth management, were followed (Jost et al. 2004).

Determination of the critical period of weed control uses two similar studies to define the weed-free intervals (Buchanan 1977). The first study determined the beginning of the critical weed-free period because plots were maintained weed-free for the initial 2, 4, 6, 8, and 10 wk of the growing season. After these intervals, natural populations of Benghal dayflower reinfested the plots. The companion study defined the end of the critical weed-free period; Benghal dayflower competed with cotton for the initial 2, 4, 6, 8, and 10 wk of the growing season; after which, Benghal dayflower was removed. Every 7 d, Benghal dayflower was removed from appropriate plots, through a combination of cultivation and hand-weeding. Treatments also consisted of a weed-free control and a weedy control.

Cotton plant heights and canopy widths were measured every 2 wk until canopy closure in 2004 and 2005. Biomass and number of Benghal dayflower plants were sampled before initiating weed-free treatments in 2004 and 2005. Cotton yield was machine-harvested in 2003 and hand-harvested in 2004 and 2005. Data were subjected to ANOVA. Time after crop planting was converted to growing degree days (GDD) using a base temperature of 15.5 C and an average of maximum and minimum temperatures measured at a soil depth of 2 cm (Webster et al. 2007). Nonlinear regression models were fit to the cotton yield data (Knezevic et al. 2002). Linear regression models were fit to Benghal dayflower plant biomass as function of GDD. The slopes of the linear regression models were compared using a t test (Glantz and Slinker 2001).

Results and Discussion

Weedy Duration. In 2003, maximum yield loss because of Benghal dayflower interference was 45% (Figure 1). There

was nearly an inverse linear relationship between cotton yield and duration of Benghal dayflower interference from the beginning of the season. There was a rapid change in cotton yield loss between 2 wk after planting (WAP) (12% yield loss) and 6 WAP (35% yield loss). Benghal dayflower population density at the time of removal at 2 WAP averaged 11 plants m^{-2}, whereas, at 6 WAP, the density increased to 37 plants m^{-2}. Previous research has demonstrated that Benghal dayflower emergence occurs later in the growing season than most other summer annual agronomic weeds, with the majority occurring after June 1 (Webster et al. 2006). The 2 WAP treatment was the second week in May, whereas the 6 WAP treatment coincided with the second week of June in 2003. Durations of Benghal dayflower interference between 6 and 12 WAP reduced cotton yield 35 to 45%.

There is an extended growing season for cotton in southern Georgia, which provides flexibility in cotton planting dates that ranges from late March through early July. There were two planting dates in 2004 and 2005, the first in early May, before significant Benghal dayflower emergence, and the second in June, during the peak emergence time for this weed. There was an approximate inverse linear relationship between yield of May-planted cotton and duration of Benghal dayflower interference in 2004 and 2005 (Figures 2 and 3). Benghal dayflower interference for the initial 8 wk of the growing season reduced May-planted cotton yield less than 10%. The maximum cotton yield loss because of Benghal dayflower interference in May-planted cotton was 21 to 30%. In contrast, yield loss in June-planted cotton was approximately double that of May-planted cotton (Figures 4 and 5). Yield reduction in June-planted cotton because of Benghal dayflower interference for the initial 4 wk of the growing seasons was 24 and 10% in 2004 and 2005, respectively. Maximum yield loss in June-planted cotton because of Benghal dayflower interference was 60% in 2004 and 40% in 2005. Other studies reported that maximum reductions in cotton yields because of season-long weed interference from various species ranged from 40 to 80% (Brown et al. 1985;
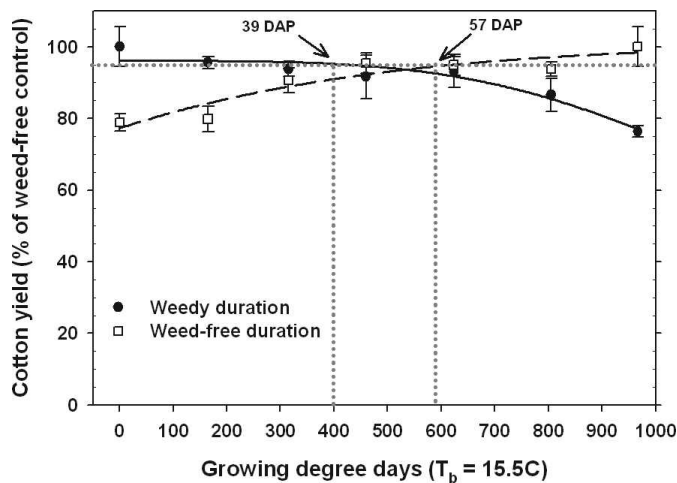
Figure 3. The relationship between May-planted cotton yield in 2005 and duration of both Benghal dayflower–present ($y = 96/[1 + (X/1,396)^{3.8}$; $R^2 = 0.45$, $P = 0.0050$) and Benghal dayflower–free intervals ($y = 101 \times \exp\{-\exp[-(x + 565)/432]\}$; $R^2 = 0.54$, $P = 0.0100$). The dotted horizontal line indicates 5% yield loss. The critical period of Benghal dayflower control is defined by the position at which each of the regression curves intersects the 5% yield line; the beginning and end of the interval is indicated in days after cotton planting (DAP).

Bryson 1987; 1990; Green et al. 1987; Mercer et al. 1987; Riffle et al. 1989; Rushing et al. 1985a,b; Smith et al. 1990; Wood et al. 1999).

Weed-Free Duration. Cotton yield increased with weed-free duration in a nearly linear manner for all years and planting dates. Benghal dayflower control for the initial 6 wk of the growing season resulted in cotton yield losses of less than 5% in 2003 (Figure 1) and in May-planted cotton in both 2004 (Figure 2) and 2005 (Figure 3). This same interval in June-planted cotton reduced yields 15 to 16% (Figures 4 and 5). This 6-wk interval is significant because previous research determined that S-metolachlor, the primary herbicide tool for Benghal dayflower in cotton, controlled Benghal dayflower at
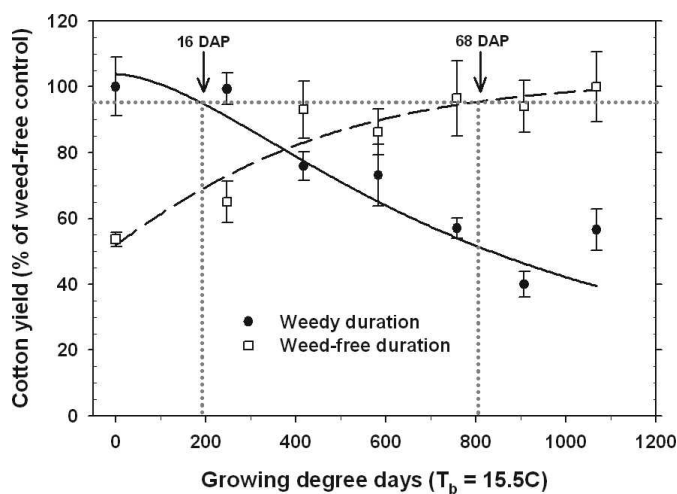

Figure 4. The relationship between June-planted cotton yield in 2004 and duration of both Benghal dayflower–present ($y = 104/[1 + (X/796)^{1.67}$; $R^2 = 0.86$, $P = 0.0020$) and Benghal dayflower–free intervals [$y = 103 \times \exp\{-\exp[-(x + 137)/356]\}$; $R^2 = 0.89$, $P = 0.0018$]. The dotted horizontal line indicates 5% yield loss. The critical period of Benghal dayflower control is defined by the position at which each of the regression curves intersects the 5% yield line; the beginning and end of the interval is indicated in days after cotton planting (DAP).
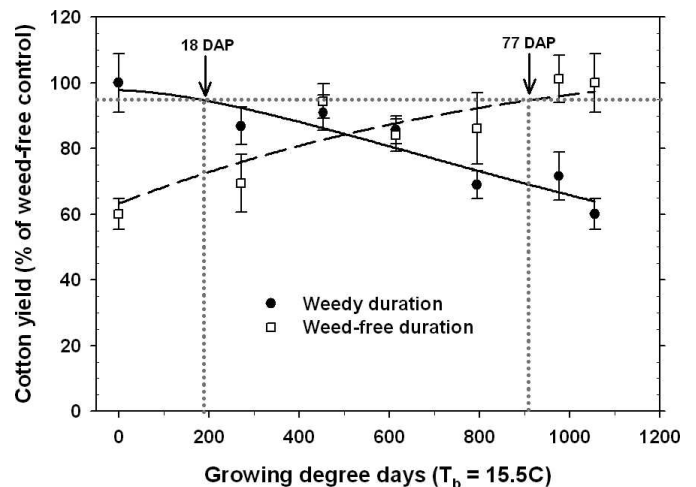

Figure 5. The relationship between June-planted cotton yield in 2005 and duration of both Benghal dayflower–present ($y = 98/[1 + (X/1,561)^{1.63}$; $R^2 = 0.89$, $P = 0.0001$) and Benghal dayflower-free intervals ($y = 109 \times \exp\{-\exp[-(x + 408)/664]\}$; $R^2 = 0.86$, $P = 0.0002$). The dotted horizontal line indicates 5% yield loss. The critical period of Benghal dayflower control is defined by the position at which each of the regression curves intersects the 5% yield line; the beginning and end of the interval is indicated in days after cotton planting (DAP).

least 90% at 6 wk after treatment (Webster et al. 2006). In peanut, Benghal dayflower reduced yield 15 to 50% when the crop was maintained weed-free for only the initial 6 wk of the growing season (Webster et al. 2007). Other studies in cotton indicated that common cocklebur (*Xanthium strumarium* L.) and coffee senna [*Senna occidentalis* (L.) Link] weed-free intervals for the initial 6 wk of the growing season reduced yields 3 to 14% (Higgins et al. 1986; Snipes et al. 1987), similar to results of the current study.

Critical Period of Weed Control. The CPWC represents the time during which weeds must be controlled to avoid an assigned level of crop yield loss, which is often 5% (Bukun 2004; Evans et al. 2003; Tingle et al. 2003; Webster et al. 2007; Williams 2006; Williams et al. 2005). In 2003, a weed-free period between 110 and 730 GDD (64-d interval beginning at 11 d after planting [DAP]) resulted in 5% yield loss (Figure 1). This interval was similar to that from June-planted cotton in both 2004 and 2005 (Figures 4 and 5). The CPWC for June-planted cotton occurred between 190 and 800 GDD in 2004 (52-d interval beginning at 16 DAP) and 190 and 910 GDD in 2005 (59-d interval beginning at 18 DAP). In contrast, the May-planted cotton in 2005 had a narrower interval of 396 and 587 GDD (18 d) that occurred 3 wk later in the growing season (initiated at 39 DAP) (Figure 3). May-planted cotton in 2004 did not have a required critical range of weed-free conditions; instead, a single weed removal between 459 and 517 GDD (a 6-d interval beginning 39 DAP or June 26) averted a yield loss of greater than 5% (Figure 2).

Previous cotton research indicated variable CPWC intervals. Similar to Benghal dayflower in May-planted cotton in 2004, prickly sida (*Sida spinosa* L.) in Alabama cotton did not require a weed-free interval; a single weed-control event between 5 and 7 wk after cotton emergence averted crop yield loss (Buchanan et al. 1977). In Texas, the CPWC for smellmellon (*Cucumis melo* L.) was 25 to 42 d, beginning 1 to 2.5 WAP (Tingle et al. 2003). Maximum cotton yield required common cocklebur–free intervals of 28 to 56 d
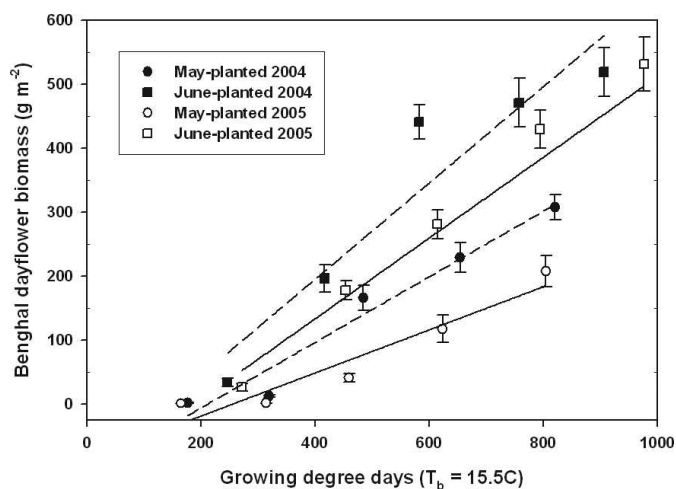
Figure 6. Linear relationships between Benghal dayflower biomass and growing degree days for May-planted cotton (2004: $y = 0.51x - 108$, $r^2 = 0.75$; 2005: $y = 0.34x - 86$, $r^2 = 0.69$) and June-planted cotton (2004: $y = 0.75x - 106$, $r^2 = 0.66$; 2005: $y = 0.63x - 119$, $r^2 = 0.71$).

Figure 7. The influence of planting date on accumulation of growing degree days in 2004 and 2005.

beginning 2 to 4 WAP (Snipes et al. 1987). Studies of multiple naturalized weed species in Greece and Turkey indicated CPWC durations of 56 to 70 d, beginning 14 to 21 d after crop emergence (Bukun 2004; Papamichail et al. 2002). Our results from June-planted cotton (52 to 64 d intervals, beginning 11 to 18 DAP) are similar to what has been reported for other species.

Competition among crop and weedy plants is a race to harvest the limited resources to the exclusion of neighboring plants. Previous studies in which weeds were allowed to emerge and establish at various intervals following crop planting determined that potential yield losses were reduced as weed emergence was delayed (Chikoye et al. 1995; Dieleman et al. 1995; Knezevic et al. 1994; Steckel and Sprague 2004). Dieleman et al. (1996) concluded that the time of weed emergence relative to the crop was more important than weed density when recommending a herbicide control program. Manipulation of crop planting date has been inconsistent in minimizing the level of weed interference. In Arkansas, soybean [*Glycine max* (L.) Merr.] yield loss doubled as planting date was delayed from early May to early June when competing with ivyleaf morningglory (*Ipomoea hederacea* Jacq.) or sicklepod [*Senna obtusifolia* (L.) H. S. Irwin & Barneby] (Klingaman and Oliver 1994). However, these planting dates with the same weeds had no affect on cotton yield (Klingaman and Oliver 1994). In another study, soybean planting dates of April, May, and July did not affect the ability of common cocklebur to reduce crop yield (Rushing and Oliver 1998). Crop planting date may affect the competitive balance between crop and weed, but success will depend upon environmental conditions and the biology of crop and weedy species (Norsworthy and Oliveira 2004; Williams 2006). Cotton plants are inherently slow to establish following planting (Buchanan and McLaughlin 1975). The May-planted cotton of 2004 and 2005 permitted this period of slow growth to occur before peak Benghal dayflower emergence and growth. Benghal dayflower biomass accumulation between 2 and 10 wk after cotton emergence increased in a linear manner with GDD (Figure 6). The rate of Benghal dayflower growth was greater ($t > 3.50_{6df}$) in June-planted cotton compared with May-planted cotton. This higher rate
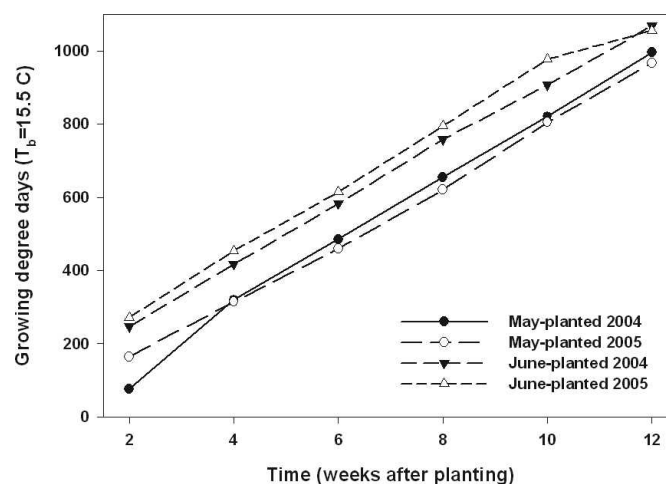
of Benghal dayflower growth in June-planted cotton resulted in greater cotton yield loss relative to May-planted cotton. June-planted cotton accumulated 70 to 100 and 90 to 170 more GDD at each harvest date relative to May-planted cotton in 2004 and 2005, respectively (Figure 7). Benghal dayflower is native to tropical Asia and Africa and thrives in hot and moist environments (Kaul et al. 2002; Webster et al. 2005; Wilson 1981). The combination of higher Benghal dayflower growth rate and greater GDD accumulation with June-planted cotton relative to May-planted cotton resulted in greater yield loss because of Benghal dayflower interference. Benghal dayflower biomass was two to six times greater in June-planted cotton compared with May-planted cotton for the same time interval following cotton emergence (Figure 6). Therefore, it is recommended that fields infested with Benghal dayflower should be planted with cotton early in the growing season to minimize the potential impact of Benghal dayflower on crop yield. This is an example of the application of weed ecology knowledge to improve weed management (Buhler 2002; Cardina et al. 1999; Forcella 1997; Zimdahl 1999).

Another gauge of the relative competitiveness of interaction between cotton and Benghal dayflower is reflected by the point where the regression curves intersect, which represents the minimum yield loss associated with a single control measure. This optimally timed control measure in May-planted cotton in 2004 and 2005 occurred at 495 GDD (June 30, 43 DAP) and 530 GDD (July 5, 54 DAP) and resulted in a 5 and 6% yield loss, respectively (Figures 2 and 3). In contrast, yield losses ranged from 16 to 21% in 2003 (370 GDD, June 10, 41 DAP) and in June-planted cotton in 2004 (360 GDD, July 19, 36 DAP) and 2005 (490 GDD, July 30, 42 DAP) (Figures 1, 4, and 5).

Determination of the CPWC has been advocated as an important means of optimizing POST herbicide control, especially in glyphosate-resistant crops (Knezevic et al. 2002, 2003; Martin et al. 2001). However, there are currently no effective topically applied herbicides in cotton that will selectively control emerged Benghal dayflower plants larger than 6 cm (Culpepper et al. 2004). These CPWC data could be used to time physical control measures (e.g., cultivation); however, the effectiveness of cultivation is not clear because of Benghal dayflower's ability to regenerate following simulated cultivation (Budd et al. 1979; Burton 2005). The most

effective herbicide control measure will include *S*-metolachlor applied before weed emergence, but POST to the crop, along with proper soil moisture for herbicide activation (Culpepper et al. 2008; Webster et al. 2006).

Although CPWC will help to maximize the effectiveness of weed control tactics, in terms of the benefit on crop yield, there are instances when rigorous Benghal dayflower control programs may be required. Aggressive monitoring and control programs for Benghal dayflower must be instituted in areas susceptible to invasion because of the difficulty and expense of managing naturalized high population densities of Benghal dayflower. The presence of Benghal dayflower on the U.S. Federal Noxious Weed List restricts movement of this species, alone or as a crop-contaminant, across state borders, which further increases the complexity of management if raw products must cross state lines. In addition, Benghal dayflower is an alternate host for several soilborne plant pathogens and nematodes, which could have a deleterious impact on crop rotations aimed at reducing these pests (Davis et al. 2006; Desaeger and Rao 2000; Mbwana et al. 1995; Narendra and Rao 1973).

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